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Granular Synthesis Composition with StochGran and Max

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Abstract—An approach to composition and the granular synthesis techniques used to create several works will be discussed here. Three instruments for stochastic granular synthesis have been written in the Cmix programming language. The contents of the grains are either synthesized waveforms, or sampled sound files. A NeXT graphical interface to the Cmix instruments, StochGran, currently allows the composer to manipulate graphical envelopes to control grain timing, frequency, and location parameters over time. Control over several parameters in a coordinated relationship is facilitated by the graphical display. The use of the Cmix instruments and interface in composing several works for tape is described. Real time granular synthesis is also explored using the MAX language on the IRCAM Signal Processing Workstation. The work "Evolutions," for eight instruments and computer, uses a combination of Cmix and MAX signal processing. The consequences of these techniques for composition and performance involve differences in composition for and perception of the computer and acoustic parts, the interaction between the computer and instruments, "musicality," timbral shaping into gestures, and philosophical implications of the techniques.

Keywords—Granular synthesis, Cmix, StochGran, MAX, Composition, Interface, NeXTstep, ISPW, Timbre, Gesture.

1. INTRODUCTION

This paper will attempt to explain my work with granular synthesis. First, the basic technique and history of granular synthesis will be briefly described. My intention was to create fully stochastic granular synthesis instruments, using both wavetable and sampling sources. The creation of compositional tools was, of course, in order write music, and several pieces will be described written at various stages of writing the software. The graphical elements which added enormously to the control capabilities of the software, and the real time aspects of the MAX version, which created new relationships for the performance situation between live instruments and computer, are considered. Finally, the influence of the techniques on the meaning of the music will be discussed.

2. BACKGROUND

2.1. The Basic Technique

Granular synthesis is windowed sound. Complex sounds are made up of "grains" or small segments of sound, added together. The grains may be less than 1000 ms, hence the name, or much larger. Each grain may contain a waveform synthesized from a wavetable or a sampled sound. Because a wide range of sounds can be created from simple waveforms, a sine wave is often used in synthesis, although other processing such as frequency modulation can be used.

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Each grain usually has an envelope, which is often triangular, to avoid clicking or extraneous noise. The frequency/transposition of the grain affects the perceived pitch of the resulting sound, as does the grain rate. Density and grain frequency/transposition affect sound color, or timbre, of the resulting sound. Density depends on both grain rate and grain duration. The phase of the grains will also effect timbre, as more complex waveforms will be produced by adding together out-of-phase grains.

The arrangement of grains can occur evenly, but is often modified by some stochastic process. The rate, duration, and frequency of the grains might occur within particular ranges rather than at a single value. The stochastic modification of grain parameters allows drastic change in the sound produced. For example, a "roughness" in the sound may become more noticeable when the grain rate is more variable, because there may be small portions of the sound when no grain is being played.

The resulting sounds have much timbral variety. In addition, control over timbral change is possible by modifying simple parameters. Synthesis with a sine wave has the advantage that complex grain arrangements can be heard more clearly than when a brighter or more complex source sound is used. On the other hand, sampled sounds may be used because it is one way that concrete material can be modified over time in a continuum from the original sound to an extremely altered sound, or vice versa.

2.2. History

Gabor's acoustical theory [1] first stated that any sound could be described by a composite of grains of sound. Bastiaans proved this mathematically in 1980 [2]. Therefore, a sound synthesis technique involving addition of grains could produce virtually any sound. Xenakis described a form of additive synthesis organized by screens, frequency-amplitude cells containing grains, to control sound evolution [3]. In 1965, Roads implemented a Music V granular synthesis instrument [4], and Truax has created compositions using granular synthesis with real time computation [5,6]. Currently, granular synthesis is also being explored by composer J. Piche, Lippe [7], Orton [8] and others to create compositional material. The solution of how to control the grain data has varied, as some composers use stochastic equations while other do not, and some work with solely short grain durations while others include longer grains.

2.3. Software Platforms

Lansky's music programming language, Cmix [9], allows the user to create instruments which control the sample generating process on as many levels as necessary, therefore being an ideal platform for granular synthesis. The sample-generating loop can have subloops to write individual grains with any timings specifiable in C. Since a real time computation for this work was not necessary, as many grains as desired could be layered. The combination of NeXTstep graphical interface with Cmix or NeXT music kit programs was useful for programmers of public domain music composition tools because of the ease of creating the interface, with its object-oriented Interface Builder.

3. GRANULAR SYNTHESIS SOFTWARE DESIGN AND COMPOSITIONS

The intention was to create granular synthesis programs with precise control over the stochastic parameters. First, the ability to do stochastic granular synthesis in the Cmix programming language was desired. Then, when I started to do graphical work and used the NeXT, I wanted a more spontaneous compositional process, to work more visually and avoid typing into data files and running command line arguments. The need for sampled sound for the grain waveform occurred when acoustic sound, including instrumental sounds, were required for a piece. Finally, for a more flexible performance with instruments, real time programs were required.

3.1. Implementation in Cmix/NeXTstep

3.1.1. "sgran"

The first Cmix granular synthesis instruments ("gran" and "mgran"), written by Garton, synthesized a series of grains of a particular rate, frequency and duration, and could move from one set of grain parameters to another set over time. Some of the effects of these instruments are similar to amplitude modulation, while some are unique to granular synthesis. Another instrument by Garton and Milburn ("gravy") took an input soundfile and transposed it by a certain amount, outputting the results in a windowed form as in granular synthesis, in order to time-stretch independently of transposition. I was interested in having the ability to control all of the parameters with probabilities, making rate and window duration more independent, and changing the parameters over time, and so wrote new instruments. In "sgran," a simple probability function produced values in a shape resembling a normal distribution, when given a low and high limit of a range, and a midpoint around which to cluster by an amount of "tightness." All of the grain parameters are controlled with this function. When using "sgran," one specifies the low, mid, high, and tightness values for variations in rate, duration, frequency, and location. The four values are specified for both the "low" and "high" possible in the series of grains to be calculated. Four functions define the shape of change between low and high values over the course of the event. The functions are defined in a Cmix "makegen" statement, which allows linear, exponential, or other shapes, and over 250 breakpoints (see the Appendix). The new stochastic "sgran" could create many more varied timbres than the previous instruments.

3.1.2. "Song for Earth Day"

The composition using "sgran" was created in about one week, around Earth Day, 1990. I found that the granular synthesis instrument I had written could simulate a moving filter, creating narrowing or widening bands of sound, and also that it could simulate natural sounds like running water or thunder.[1] The most powerful aspect was that any one sound could be transformed to any other with a control over the change in parameters. The piece became a tribute to Earth Day, to encourage listeners to appreciate the richness of the natural environment, even in music created on a computer.

3.1.3. StochGran

Thirty-six parameter fields and six functions for each event created a need for a higher level graphical control of the sgran parameters. With the NeXTstep Interface Builder, this control was not difficult to achieve. As described in [10], StochGran (Figures 1–3) has form fields for each parameter, and radio buttons to define waveform and function descriptions. The interface would hold data, which was now easily modifiable without the problems of syntax. Each time new data was to be tested, it could be written out, with only the minor changes necessary for a new sound sent from the interface (Figure 2). Each data set or score could be saved separately for later use. The interface wrote out the text score file, ran the Cmix program with the score, rescaled the soundfile to integers, and played the resulting soundfile (Figure 1). Suddenly composing was more spontaneous. Small variations in values could be quickly tested and saved to different files, so that it was easy to create and store subtle transformations in different soundfiles. Because the score files could also be saved, later modifications could be made to the text file and rerun when needed.

Part of a sample "sgran" score written out by StochGran's ScoreWriter object:

```
/* /me/water.snd    (This is a comment with soundfile name and description
```

[1] On the day of an outdoor Earth Day concert I missed to work on the piece, I found sounds of the earth coming from the program I had written.

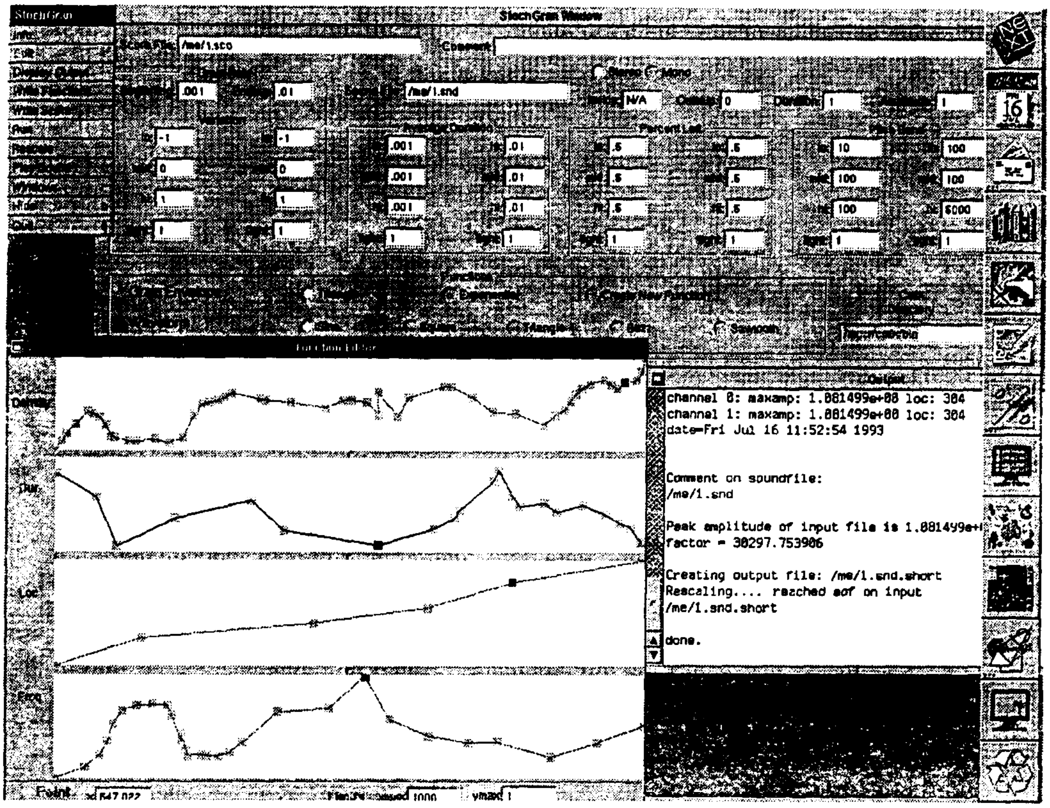

Figure 1. The StochGran main, function editing and output windows.

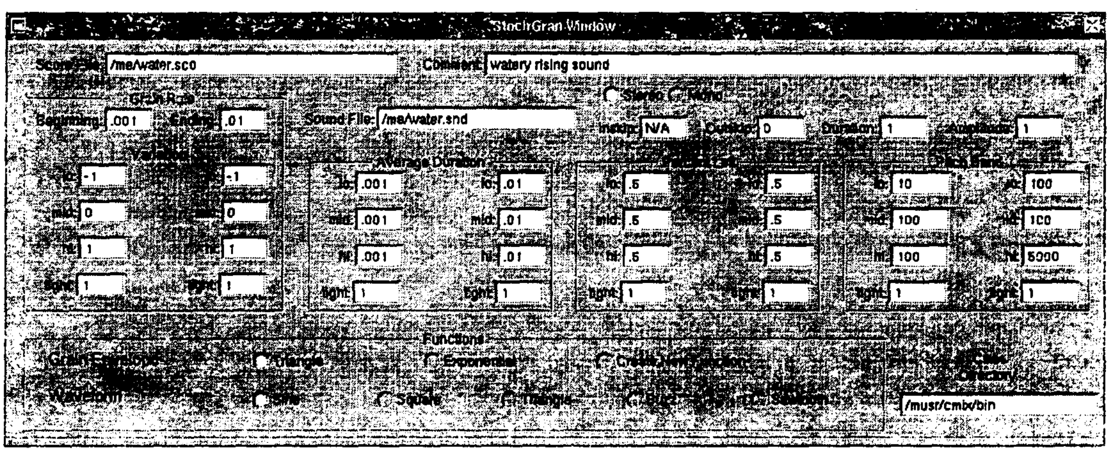

Figure 2. The main StochGran window with low and high grain parameter settings, including grain rate, frequency, amplitude, and duration. The grain waveform is selected with a radio button.

```
watery rising sound */
output("/me/water.snd",0)    // (This is the name of the output sound file.)
sfclean(0)
// The following makegens control the shape of change in frequency,
//grain rate, location and duration throughout the event)
makegen(1,7,512,0,256,1,256,0)
makegen(2,7,1000,0,87.774292, 0.146000,20.375710, 0.136000,23.511009,
0.340000,26.645996, 0.223000,72.100998, 0.087000,79.936996, 0.388000,7.837006,
0.699000,54.859009, 0.447000,7.837006, 0.194000,1.566986, 0.282000,3.135010,
0.087000,68.964996, 0.272000,26.645996, 0.379000,15.674011, 0.505000,42.319977,
```

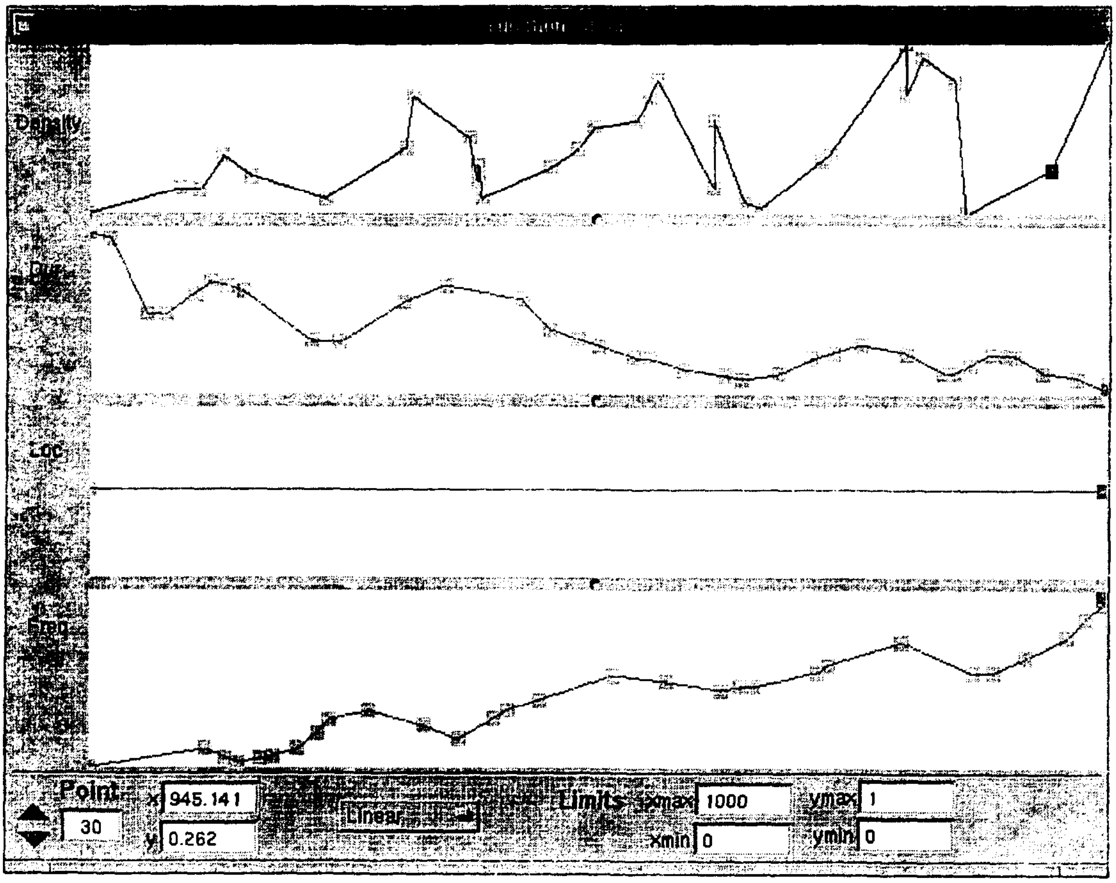

Figure 3. The functions which control modulation of grain parameters between low and high settings as the event unfolds are defined graphically.

```
0.553000,10.972046, 0.680000,9.403992, 0.796000,54.859009, 0.146000,0.000000,
0.563000,29.781006, 0.068000,15.674011, 0.029000,61.127991, 0.320000,6.269714,
0.350000,76.802246, 1.000000,0.000000, 0.718000,15.674011, 0.922000,31.348022,
0.786000,10.971985, 0.000000,3.135010, 0.000000,79.937012, 0.262000,54.858948,
1.000000)
makegen(3,7,1000,1072611459,20.376001, 0.931000,36.050001, 0.471000,17.242004,
0.471000,28.212997, 0.598000,17.241005, 0.667000,15.673996,
.
.
.
// This describes a sine wave, the grain waveform:
makegen(6,10,1024,1)

//This is the call to "sgran", with timing values specified:
sgran(0,1,1,
/*grain rate values:*/
.001,.01, -1,0,1,1, -1,0,1,1,
/*duration values:*/
.001,.001,.001,1, .01,.01,.01,1,
/*location values:*/
.5,.5,.5,1, .5,.5,.5,1,
/*pitch values:*/
10,100,100,1, 100,100,5000,1)
```

The function panel in the new version of StochGran allows the user to modify the shape of change functions graphically. Fernando Lezcano's EnvelopeView provided a graphical object for the view into which the functions are drawn. One can see the four shape of change functions aligned in time, and create relationships between the functions which evolve as each event of grains unfolds. For example, in Figure 3, the frequency moves in an uneven line gradually upward from the "low" value to the "high" value throughout the event. The duration of grains moves inversely, gradually downward in an still more uneven line. The density, actually rate, of grains moves quite jaggedly up and down as the event progresses. In the sound, the listener will likely be aware of at least some of the relationships between parameter changes. The functions can be reused with different low and high values so that overall contours can provide a "motive" or repeated relationship, somewhat similar to the idea of augmentation or diminution in rhythm, or expansion and contraction of intervals in tonal or atonal pitched systems.

3.1.4. "Dragon of the Nebula"

The vision of a powerful space dragon out of touch with human values was a generating idea for "Dragon of the Nebula," created around the time of the Gulf War. Stochastic granular synthesis made a fast but smoothly changing series of diverse timbres possible for the last section. The idea was to maintain a continuous focus through widely varying sounds, expressing the power of ultimate transformation. The middle section used "chorusy" sounds, with large grains up to two seconds in duration, heavily layered. Since frequency, like the other parameters, is generated stochastically within a range rather than harmonically, the dense clustery sounds had unusual, inharmonic timbres which evolved slowly. Some of the layers were transposed and started at different times, producing canonic events. Room simulation programs simulated an environment in which the sound happens in the second section of grains large enough to be individually audible. The reverberation was emphasized when transposed down an octave in several places, producing an effect which sounded as though it might be heard under water. Dryer sounds occur in the middle and ending sections, indicating that the sounds may exist in a space without reflections, such as in space.

3.1.5. Algorithmic programs

While the StochGran interface was best at fine tuning grain parameters, another way of creating material for "Dragon of the Nebula" was to name some outer limits for the grain parameters, and let a program generate sounds stochastically within those limits. Again using the probability function, this time I set up the four values for each "sgran" parameter, and let the program write out hundreds of score files within these limits. After a number of tries, I found a set of parameters that made a variety of sounds. The results of running a large number of files were amazingly diverse. I found a number of good surprises, and cataloged them all for future reference. The more heavily layered dense sounds were often a changing "metallic" or "mass" sound. A series of random mixes were put together, by having a program write out Cmix mix scorefiles, to mix a number of the granular sounds together. The last section of the piece consists of these randomly mixed sounds, chosen and ordered intuitively. This combination of intuitive and algorithmic methods is efficient as new material is generated in a complex composition which would be time-consuming to program.

3.1.6. "stgran"

The next step was to incorporate sampled sound. Having heard Truax's sampled granular synthesis music, and because of my own interest in concrete sound, I wrote a sampling version of sgran called "stgran." The logic had to be rethought as now one would be stepping through an input file and needed to control input as well as output file parameters. With the input file parameters, the list of parameter fields then amounted to fifty.

Because sampled sound is much richer than pure waveforms, and especially the sine wave I previously used, the timbres produced from granulation of sampled sound are brighter and in some cases, much noisier. The phase of the sound in each grain is important in determining what the resulting timbre will be. While some granular sampling sounds may be similar to the input soundfile, others may be closer to noise. Control over the phase of the grain would make finer timbral control possible. I implemented Jones' and Parks' in-phase correlation technique [11] to line up the phases of the grains in the instrument "samgran."

3.1.7. Implementation in MAX on the ISPW

When the ISPW became available, I realized a live electronic part for "Evolutions," for eight instruments and computer. Max patches were built to read sampled sounds into grains at stochastically variable parameters. A performer at the computer could trigger granular synthesis events synthesized in real time.

The logic was slightly different from the Cmix programs because grains had to be calculated in linear order. While stochastic start times can be generated in any order in a nonreal time layering process, in a real time performance, of course, they cannot be calculated after they are supposed to occur. Processing the live instrumental sounds was attractive because the instrumentalist would have more control over the computer part, but impractical because too many hours of rehearsal would be required. Instead, soundfiles of sampled instrumental sounds were read into tables, and processed for a reliable, clean sound which was still intimately related to the instrumental sound. Another difference from the earlier programs was the limit on a number of layers which could be processed in real time, which meant voice allocation had to be as efficient as possible. Also, probability tables were used which produced values within range, but did not have the specific midpoint and clustering capabilities of the C probability function, which would have slowed down the calculations.

Four levels of granular synthesis Max patches were created. The top level control patch (Figure 4) added the outputs of four independent voices of granular synthesis, and controlled amplitude and reverb. The buttons which triggered subpatches for each section of the piece, including sections which read from already mixed soundfiles, were also on this top level patch. An example of a subpatch for the computer part during the violin entrance is in Figure 5. The sectional subpatches contained a metronome which triggered buttons with approximately twenty grain parameter values each of which were sent to the second lower level voice patch. This voice patch applied the event envelope to the stream of grains and sent the parameters into a still lower patch. This patch calculated the increment in change between each grain for each parameter by finding the number of "frames" in the total event, and dividing the difference between the ending and beginning values, by the number of frames. These increments were sent to the lowest level patch, which read from a previously filled sample table at the correct speed, transposition, rate and duration, and also applied an envelope to each grain. Metronomes generated pulses for each voice to synthesize a grain, and the combination of the four voices produced rates which could create some of the sounds realized with the nonreal time system. The touch of a button could initiate many consecutive events. A composing patch for testing parameters (Figure 6) had sliders for each grain parameter, and buttons to select transpositions or input sample tables (source sound). Sounds could be heard and easily modified with these controls.

3.1.8. A hybrid composition for instruments and live computer—"Evolutions"

The composition "Evolutions" traverses a set of timbres based on instrumental sounds. The introduction is made from granulated pizzicato cello sounds. The first part is composed of comb filtered ambient sounds with heavy room simulation, and occasional crotales notes played by the percussionist. This subtly-changing sound mass slowly forms itself into pitched sounds which come from a narrower range of transpositions of a single pizzicato note, played in reverse,

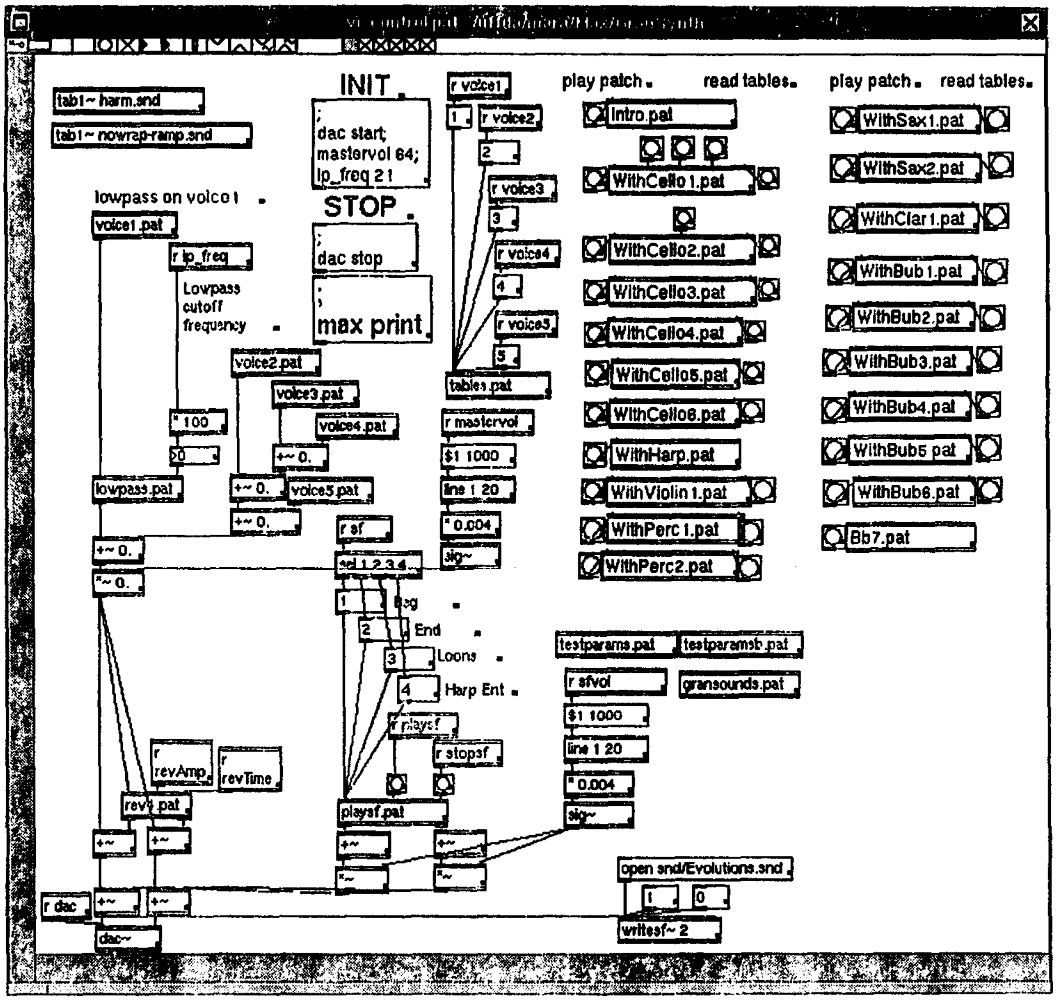

Figure 4. The main Max control patch for "Evolutions." Objects trigger reading of tables from sound files, different sections of the piece, reading soundfiles from the disk (i.e., in the Introduction), and set overall amplitude and reverberation levels.

and windowed stochastically. The windowing was all done in Cmix, with elliptical filtering and heavy room simulation to clean and deepen the sound. The resulting sounds resembled vocal sounds, and with the reversed, stretched pizzicato one hears a slowly changing emphasis of harmonics moving up the series.[2] The twelve tone row used in the piece is exposed here, note by note through one hexachord (the symmetrical 013467), building to a chord which is the other hexachord (012369) voiced with a clear dominant seventh reference. The cello enters next, with the computer part based on cello samples and expanding upon the acoustic instrument's capabilities. Each instrument in turn plays with the computer based on their sampled sounds. The timbres evolve from string sounds, cello to harp to violin, to the more noisy percussion metal sounds, and finally to the winds through the alto saxophone, clarinet, and finally to flute. this last instrumental entrance is the simplest timbre, close to a sine wave, so the progression has been from moderately complex spectra string sounds, to more complex sounds, to the simplest sounds. The flute, however, plays virtuosically in opposition to the the entire ensemble and computer. The computer part with the entrances is composed both of Cmix soundfiles, and sounds generated live by the MAX patches. The parts which require more intimate interaction between computer and instrument are performed in real time. The parts which require many hours of processing, such as the introduction, were created in Cmix.

[2]A plucked string note quickly decays from a noisy signal to the fundamental.

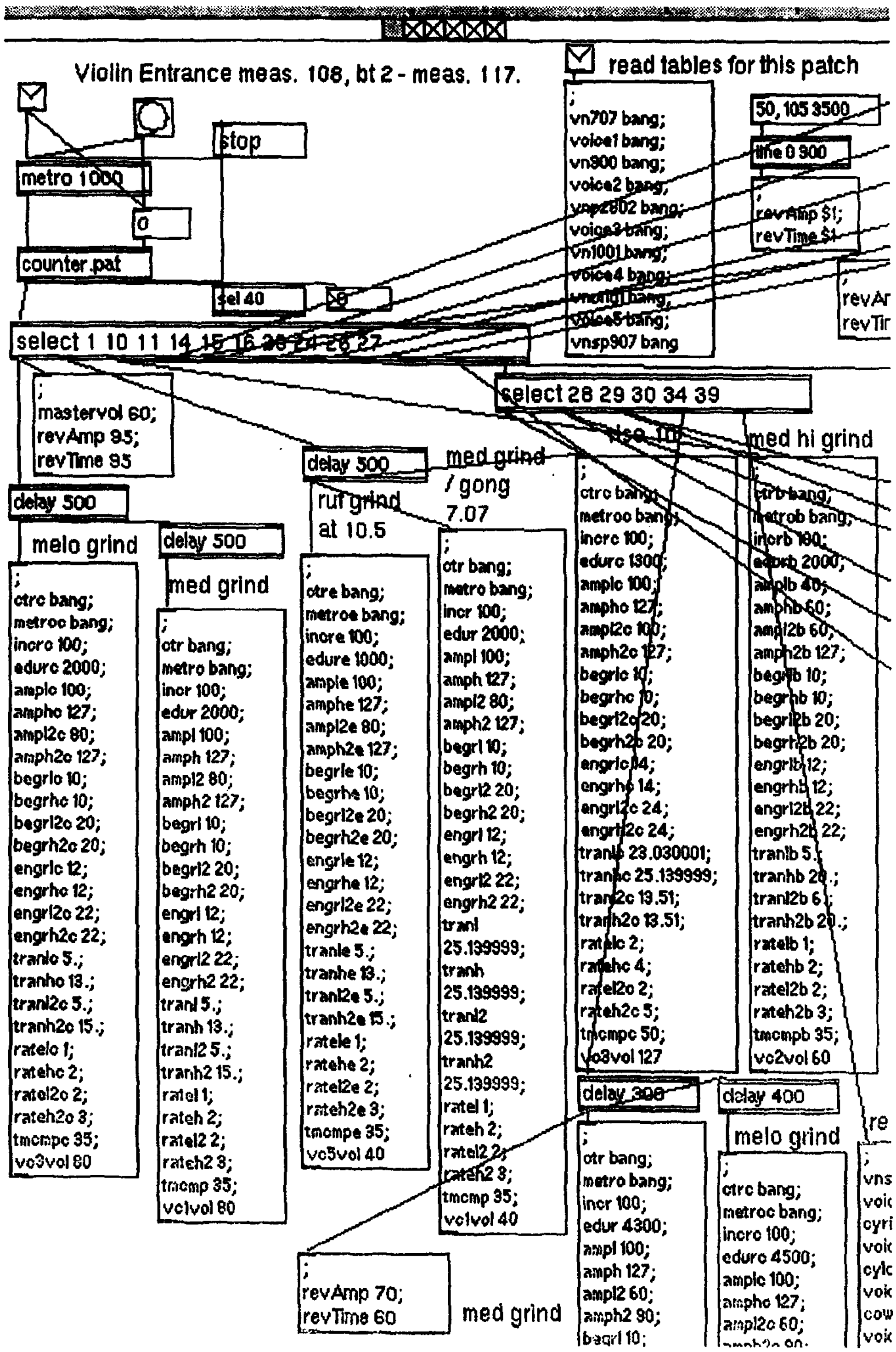

Figure 5. The patch for creating new sounds had controls for event duration and reverberation, as well as beginning and ending grain parameters such as amplitude ranges, rates, and transpositions. A portion of the patch is displayed here.

The instrumental entrances are followed by seven sections with more complex interactions between the instrumental parts, and between the instrumental parts and computer part. The timbral changes are often faster. Groups of instruments work together to form textures that may oppose or complement other groups. As in the entrances section, the computer part extends the timbral range of the instruments. The lines and shapes created by the combination of instrumental

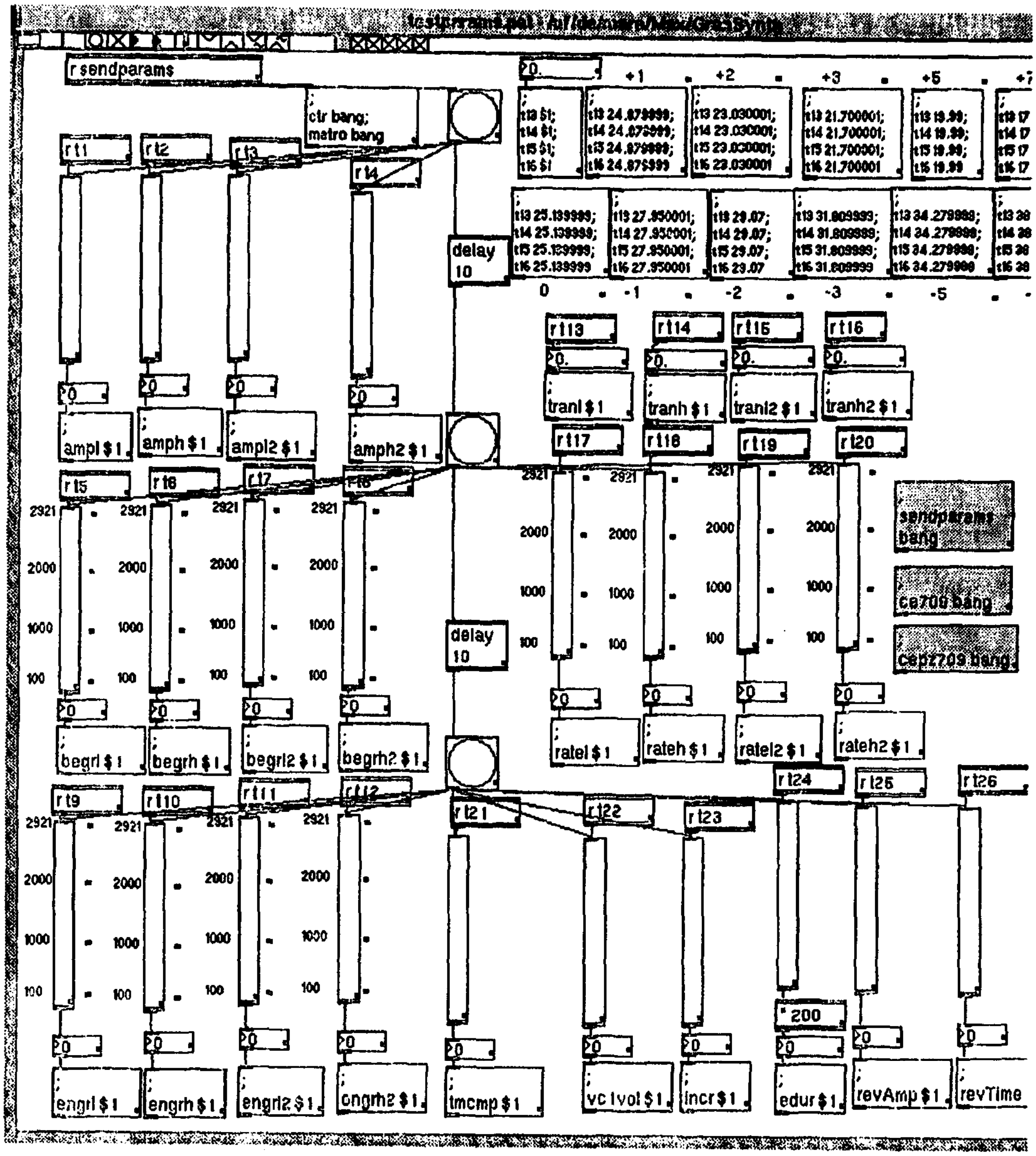

Figure 6. MAX patch for a portion of the computer part with the violin entrance in "Evolutions." The counter keeps track of the beat for the section of the piece, and the "select" objects triggers buttons with grain parameters at the correct times. The grain parameters are sent to the lower level granular synthesis patches. A portion of the patch is displayed here.

and computer parts in the second half of the piece change more frequently than earlier in the piece. The instruments form subgroups at times, and may be punctuated or embellished with computer parts unplayable by acoustic instruments, encompassing a variety of granular synthesis sounds. The sounds were organized compositionally in groups according to what similar natural acoustic phenomena might sound like, regardless of actual source. The categories for this piece included:

Natural: sounds resembling acoustical phenomena not made by people
water: high frequency range fast grains
thunder: low frequency grains
Vocal: sounds resembling human voices
nasal: often a woodwind source

"midvocal": varying pitch, often a cello pizzicato source
choral: smooth, pitched chorus sound from cello pizzicato
Mechanical: sounds resembling those made by machines
metallic: dense layering of microtonal pitches,
grains often having long durations
grinding: grains with very short durations

Each category of sound had a more particular function near the beginning of the piece. Later, these uses might interchange or become more complex. For example, in the beginning, the "midvocal" sound occurs as part of the ambient opening texture. A sense of a huge space like an old monastery with monks chanting irregularly is created from this sound. In later portions of the piece such as the cello entrance, the "midvocal" sound punctuates the cello line creating a momentary memory of the large space, but quickly dying away and leaving the cello even more exposed than it would be without this suddenly absent sound/space. The "metallic" sound is used in the middle of the piece before the first climax as a punctuation. The instrumental lines are building in density, and quick interruptions which display a tremendous density, thousands of layers, increase the tension of the building phrases. Later there are more developed "metallic" sounds which transform more delicately and slowly, creating phrases of their own. This extension and transformation is similar to motivic development in tonal music.

In addition to sampled instrumental sounds, another concrete source is used: loon calls. These sounds were chosen for their relationship to the natural sounds created by granular synthesis, their "transformability" by granular synthesis because of the simplicity of their timbres, because they may be imitated by the wind instruments, particularly clarinet, and most importantly because of their haunting quality. This reclusive bird exists in places avoided by humans, yet makes evocative sounds that resemble a variety of human emotional responses, including a maniacal laugh and a mournful wail. It seemed an appropriate reflection of or comment on the human life expressed in the instrumental parts, as the computer, which performs the loon calls, often opposes them.

The computer also creates environments with room simulation. Scott's Cmix programs "place" and "move" [12] add reverberation which indicates particular room sizes, and source and listener locations. When the instruments play with the computer, the room simulation affects perception of the instrumental parts as well as the computer part which is modified directly. The interaction of several rooms, one the hall in which the piece is played affecting particularly the instrumental sounds, and also the artificial spaces created with processing, composes a multidimensional world. The introduction seems to occur in a huge space with ambient sounds and moves to a more focused set of pitched sounds still implying a large room. The computer part in the instrumental entrances section uses a reverb patch with less specific effects, and may change quickly within phrases from heavy to no reverberation. In the sections after the entrances, some Cmix "place" with specific and widely varying room simulation effects occur, along with many very dry sounds implying an intimate space.

4. COMPOSITIONAL ISSUES

In the writing of "Evolutions," aspects of concern included strategies for realizing and performing the computer material, and the relationship between computer and instrumental parts. Concerning the work as a whole, the gestures and evolution of timbre are primary compositional elements which have aesthetical implications to be discussed in the following sections.

4.1. Real Time Versus Nonreal Time Strategies

Performance of granular synthesis sound involves either playing a tape or live processing. Tape music possesses all of the processing capabilities of nonreal time synthesis. In a live performance situation, tape music can explore sound and space uncompromisingly due to virtually unlimited

processing time. My preference as primarily a tape music composer is to make use of this freedom rather than sacrificing control for the limitations of MIDI or other live performance systems currently available. However, for some music, live performance is a desirable feature. While it is true that each listening situation is in a different context including sound system, performance space, nearby simultaneous events, and mindset of listener, still essentially the same sound waves emanate from the playback equipment each time. The ability of the mind to habituate to repeated stimuli has been noted by psychologists. While good tape music can retain life regardless of repeated listenings, live performers may relate better to an electronic part which varies in performance and rehearsals. One of the positive aspects of working with the real time system described here was that every time a certain event was produced by clicking a button, it was slightly different due to the probability tables. A sense of "aliveness" was much easier to obtain with this variability, at least during composition. Perhaps because we are used to living in a changing and unpredictable world, it can seem more "natural" to work with a less fixed medium. The technical difficulties have made real time timbral composition difficult, as MIDI control is limited, and other systems are rare, not standardized (which makes performances unlikely), or difficult to use. In addition to availability, there are other positive aspects of non-real time mediums. Since the pressure to "perform" or keep up with the listener's perception in the creation of the piece, one can thoughtfully make all decisions in order to keep the integrity of the piece. The sections of "Evolutions" created in Cmix took on a particular shape early on, and when finished, had realized the original idea clearly. This clarity was particularly important for the structurally important points, climaxes, introduction, and ending. Other sections, which developed particular instrumental sounds, demanded close interactivity between the instrumental and computer parts, and therefore worked best with a live computer part. At times, the instrumental part would play a sustained pitch, while the computer part would fade in with the same granulated pitch, and then widen out to a frequency band of many pitches surrounding the original instrumental pitch. The timing of the computer's crescendo was critical to perceive the continuity of the event. Unless an instrumentalist's performance with tape was extremely precise, the computer part would be more likely to be correctly timed if triggered by a computer performer. It is not difficult for an instrumentlist to synchronize with a tape if his/her attacks follow clearly recognizable computer events. If the computer part is amorphous or subtly changing as with gradual timbral changes, a performer who could also react to the instrumentalist's part would add flexibility to the performance. The choice between maximum control or performance spontaneity was made according to the material and primary function of the musical section.

4.2. Computer and Instrumental Composing

The computer part and instrumental parts are by nature quite different. If the computer part is tape, audiences used to watching live performers sometimes miss their presence. Various performance contexts have been created specially for tape music, for example at Columbia University [13]. If the computer part is live, the computer performer, here using a mouse, has limited performance control. The instrumental part, however, is played by a human being, with much direct control over the sound being produced. The listeners are intimately aware of how the performance unfolds and the physical relationship between the instrument and performer. This drama influences the perception of the music, and is part of musical expression. The visible efforts made by the performer to complete a difficult passage are seen and appreciated by the listener. If s/he plays well, and also generates empathy in the listener for dramatic reasons, the perception of the music is doubly appreciated. Because this performance drama is missing or limited for the computer part, the audience is likely to perceive it as more abstract than the instrumental sounds. The computer sounds might be more closely associated to the mind or mental processes, while the instrumental sounds might be linked to the body, as they are intimately tied to the performer's breathing and movements. While of course good performers can express abstract ideas on acoustic instruments, and good tape music can emote, still these connections

are encouraged by the performance situation where the listener watches the instrumentalist. In "Evolutions," the performers surround the audience, making the audience even more aware of their physical connections with the created sound.

More importantly than the drama of instrumental performance, the tradition of musical composition and performance is omnipresent in the current performance. The years of simultaneous development of the instrument and idiomatic playing techniques in music have created a network of musical languages and movements which a trained musician learns. When the musician communicates in these languages a message the listener wants to hear, their playing is called "musical," "expressive" or "enjoyable." If the player expands the network of understandable musical language, s/he must define the new terms and establish the relationships in performance.

The computer part, whether or not controlled by a performer, contains a software component which is entirely configurable. While the software is created by a musician who may be a product of the musical tradition, the working with the computer adds one aspect to the classically trained musician: deeper awareness. Every intuitively "musical" aspect which is written into the software must be defined logically in the software language. This means that the aspect will be consciously examined and evaluated in terms of the ideas or music s/he is creating. Instead of tacitly accepting an intuitive "musicality," the composer will weigh each relationship with the time to program it, the effect in the music, and possible other relationships that might be more interesting. The virtually unlimited software component can perform mathematical equations, run neural networks, control values stochastically, create fractal processes or mix recorded sounds. When new relationships are composed into the software, a new musical language is initiated. Because the computer's idiomatic arenas are mathematics, science, and logic, the new language may incorporate more abstract understandings of our world. Computer music is particularly suited to expressing ideas beyond the emotions, from a level of awareness based on one's philosophy. From this higher level, new realities can be created which have their own emotional and sensual relationships, and which may ask us to listen in a new way. The new relationships in the music may stimulate or challenge our ideas about our existing world.

For one seeking to move beyond the tradition, with an awareness of what has been done, a computer and instrumental composition forces a new perspective on music as we know it. With the ultimately configurable computer performer, which is not even very capable of producing simple instrumental music well, the automatic and unaware connection to the tradition is broken, leaving the door open for a new music.

4.3. Relationships between Computer and Instrumental Parts

In "Evolutions," the computer part had an evolving relationship to the instrumental parts, working sometimes as an extension of the instruments, or in opposition to them. The computer might create an environment in which the instrumental sound could exist, or modify the instrumental sound by the addition of related layers of sound. The computer sounds were created directly from sampled instrumental sounds to create a continuum ranging from sounds closely tied to human performance, to highly modified sounds. With the interaction of instrumental and live computer parts, one can refer to both more concretely human activities, and to more abstract manipulations within one phrase, in opposition or complementarily, and through a diversity of textures and forms. This dual development provides another compositional dimension of expression.

4.4. Timbral Development in "Evolutions"

I was interested in the evolution of a sound object through many forms in time. Denis Smalley has described various types of sound evolution as "spectromorphology" [14]. By sound object, I mean a collection of frequencies heard as a unit, given an almost physical representation through range, density, distribution of frequencies and their relative amplitudes, and localization

characteristics. The first ambient background was a foreshadowing of the object's existence. It took definite shape in the pitched choral sounds, and then expanded into instrumental timbres, through strings, percussion and winds. During this time the sound object would refer momentarily to past or more complex versions of itself by layering or time displacement on micro and macro levels. Continuing to spin out more and more diverse timbral expansions, the more dense instrumental sections was punctuated or layered with computer timbre alterations and additions. After one climax, the sound object transforms into singular loon calls before continuing the exuberant timbral transformations from the mechanical sounds to other natural world sounds. This evolution characterizes a world view perhaps close to Taoism, encompassing the importance of emptiness, or unforced action in the ambient beginning sounds, a respect for natural processes in the bird and other nature sounds, and in the suggestion of a generating force which is impersonal, omnipotent and ultimately indescribable in any language. The flexibility of transformation in timbre hints at this power better than language can. Prose is linear, and may refer to other levels through metaphor, limited by physical reality, or alliteration, and limited by the language. Music, perhaps particularly stochastic timbral music, can unfold on many levels simultaneously which relate to each other similarly, inversely, or in more complex relationships. The "sgran" shape of change functions are an example of one type of this simultaneous unfolding.

Timbral evolution is a particularly suitable parameter to express such ideas. Color, or timbre, has a complex specification involving the amplitude envelope of each frequency component over the course of the event. The relationships between frequencies can take many forms from stochastic bands to sets based on the harmonic series. "Evolutions" tends to move between pitched sets relating to the twelve tone row, and probabilities of frequencies within certain ranges. The set of motives in the piece includes row fragments as well as function shapes for frequency band changes. The pitched serial aspects allow the listener moments of stable base and clear set of pitch relationships which can be developed, imitated, and which must be subverted at times by the inharmonic stochastic material. Timbral evolution throughout the piece sometimes allows a clear expression of an equal tempered interval set, and other times demands more microtonal, dense sounds structured by the shape of their pitch and rate changes. The migration between the two musical universes allows phrasing within each system to diminate or operate subordinately according to the needs of the moment, and defines its own shape and phrase. The world described by these different relationships is expressive of this contemporary world in which education, art, and science must embrace understanding beyond the traditional Western view, including cultures which know the subtleties of microtones and glissandi, choose the colors of their instruments from Latin gourds, Korean and Chinese gongs, and African drums, and can relate the numerous subtly different finger techniques for the Chinese chin (zither) to various poetic images. As the new physics has been noted to express scientifically some ancient Taoist ideas [15], perhaps contemporary music must now assimilate aspects of music of other cultures to encourage our increased cultural communication and mutual development.

One strength of music based on dynamic, or changing, timbre [16] is its flexible range of expression. While in instrumental music before this century "notes" were identified into "parts" by means of timbre, music had a recognizable system of hierarchies. The outer lines usually dominated over inner more harmonically-oriented lines. The tonal system itself implied hierarchical pitch functions. Even with the development of serial music the equal tempered system enforced a hierarchy of the equal tempered intervals over more complex relationships, and over even the simpler ratios of just tuned pitches. Each systematic requirement created a "rule" which limited the composer's ability to express particular ideas. With the development of music using recorded sound, the composer was faced with the dilemma of upsetting the system which s/he had been trained to use, or mangling the material to fit into the system. A new system with a phrase-oriented basis, of which the elements are contours or shapes of change in parameters allows "concrete" material to be freely used, while incorporating pitch relationships as a secondary parameter.

4.5. Gestures

The word "gesture" has been used to describe musical phrase as it relates to other mediums [17], and action toward or away from a goal, "married to causuality" [14]. Gesture can imply a coordinated movement of parameters, forming a musical unit [18]. While this could include a melody, it may also include grain parameters changes throughout an event. Because the elements are likely to be continuous since the shape of change functions are often linear or exponential curves, gradual change in at least some of the parameters is one of the distinctive aspects, unlike traditional instrumental music in which the parameters usually change at the start of each new note. The definitive part of the gesture may be the beginning or end point, or it may instead be the counterpoint between one or more parameter changes. For example, in the cello entrance of "Evolutions," the computer part slides away from the cello's sustained "A," embellishing this primary pitch emphasized in this gesture. A few phrases later however, the pitched lines diverge so drastically and almost violently to wide and loud unpitched sounds, that the pitches of the chord seem secondary to the timbres which the ear hear as driving the line. In another example near one of the climaxes, a dense somewhat "metallic" sound described here as a "mass" sound, is heard frequently. It is a dense and wide cluster of pitched sounds, and is used to point to the increasing density of the instrumental parts. The gestures in this section involve this mass sound, which is both a response to the building of the instrumental parts, and also temporarily inhibits them, provoking them to an ultimately more divergent and stronger climax.

4.6. Time, Space and Sound

Xenakis says that "separability" defines space and time [19]. For example, because we know that one thing happens before another, we can then say that there is such a thing as time to distinguish them. If this is true, then a music which is capable of subtly distinguishing gradations in separability would be most capable of creating impressions of space/time with the most freedom and clarity. Perhaps the complexity of our world comes from the interaction between absolute repetition or continuum, which absolves space and time, and absolute separability or distinctiveness, which creates unpredictability. The evolution of sound on many levels, including reverberation: from pure source to the almost infinite stochastic repetition to imply a huge space with distant source, spectrum: ranging from an acoustic instrument waveform based primarily on the harmonic series above a fundamental to a computer-generated band of anarchistic sine waves, and pitch succession: from an utterance of a twelve tone row to a series of microtonal slides, and the converging or diverging movements of more than one of these aspects of sound in some organized way, creates a musical expression of physical concepts of the universe that our culture is beginning to absorb. The drive to understand the physical universe and therefore ourselves has a particular intensity today in the era of accelerated technological and scientific development. The "frozen randomness" of genetic mutation which propels evolution of the species, or the quantum reactions between elementary particles can be reflected in the evolving timbral spectrums based on probability distributions and their reverberations. Sound shapes and parameter contours shape phrases in new and yet understandable ways from a stochastically varied time. The approach taken here of stochastic controlling grain patterns in coordinated movements through events implies a world view aware of the theory of relativity of time and space.

While this expansion of scope is possibly expressible with granular synthesis, a continuous connection to the concrete reality of our everyday lives is also maintained with the use of sampled acoustic sound and live instruments. Instead of creating a music solely with an abstract vision based on philosophical or mathematical thought, the sounds must evolve to and from the sampled instrument sounds, and even from humanly performed instrumental parts, therefore using the musical language as one frame of reference. The expanded scientific view of humanity is expressed in a language with reference to previous human languages in music and sound.

5. CONCLUSION/SUMMARY

We have seen here three compositions based on several granular synthesis programs, including Cmix instruments for both synthesis and sampling, the StochGran interface and a set of MAX patches. The graphical StochGran and algorithmic programs facilitate higher level control of grain parameters. The MAX patches allowed real time initiation of sounds which made performance with instruments more easily synchronized and kept the computer part slightly different every time. The granular synthesis technique is capable of timbral flexibility and control, and therefore may be used expressively, compatibly with new understandings of the physical relationships in our universe. While higher level abstract ideas can be implied in this music, one retains a sense of connection to the immediate world and music of the present and past through the use and modification sampled instrumental and acoustic sound. The sounds of the present are heard through new reflections. When broken down into tiny alterable components, or grains, sound can reveal previously unseen colors and textures, exposing new understandings of our world.

APPENDIX

UNIX MANUAL PAGE FOR CMIX INSTRUMENT "SGRAN"

```
SGRAN(CMIX-2)        UNIX Programmer's Manual        SGRAN(CMIX-2)

NAME
     sgran - granular synthesis

SYNOPSIS
     sgran -- cmix command

     subcommands:

     sgran(p0=start, p1=dur, p2=amp,
            p3=beg_grainrate, p4=end_grainrate,
            p5-8=beg_start_var, p9-12=end_start_var,
            p13-16=beg_grain_size, p17-20=end_grain_size,
            p21-24=beg_loc, p25-28=end_loc,
            p29-32=beg_freq_band, p33-36=end_freq_band)

DESCRIPTION
     sgran generates events made of many grains of sound. The
     parameters grain rate, duration, location and frequency can
     be given beginning, ending and variability values, so the
     grains will change over the course of the event. The
     values are generated by a probability function which allows
     one to "randomly" output values between a low and high lim-
     its, and which hug a middle value by a specified amount of
     tightness. The sgran arguments are p0 through p36:
            0       start time of group
            1       duration of group
            2       amplitude
            3       beginning grain rate
            4       ending grain rate
              amount of variation in rate:
                   (percentage of grain rate, 0-1, 0=100%)
            5-8           beg: lo, average, hi, tightness
            9-12          end: lo, average, hi, tightness
              average duration:
```

```
        13-16          starting lo, average, hi, tightness
        17-20          ending lo, average, hi, tightness
          location:
        21-24          starting lo, average, hi, tightness
        25-28          ending lo, average, hi, tightness
          pitch band:
        29-32          starting lo, average, hi, tightness
        33-36          ending lo, average, hi, tightness
```

Functions 1 through 6 represent:
(all changes are linear)

```
        1       grain envelope              shape of change:
        2               grain density
        3               grain duration
        4               grain location
        5       shape of change: frequency
        6       waveform
```

The output values move from the low to the high value according to the shape of the function for the specific parameter during the course of the event.
At this point the additive synthesis version of sgran is implemented. Versions synthesizing frequency modulated grains and sampled grains with in-phase correlation are in progress.

EXAMPLE

```
        makegen(1,7,1024,0,512,1,512,0)
        makegen(2,7,512,.01,512,1)
        makegen(3,7,512,0,512,1)
        makegen(4,5,512,.01,512,1)
        makegen(5,7,512,.01,512,1)
        makegen(6,10,1024,1)
        setline(0,0, 2,1)
        sgran(0, 2, 100, .01, 1, -1,0,1,1, -.01,0,.01,1,
     .1,.1,.2,9, .1,.1,.2,2, 1,1,1,2, 1,1,1,2,      1000,
1500, 2000, 2, 800, 900, 1000, 2)
```

will create a 2-second event in which the grain rate moves from 100% to 1% possible, with grain durations continuously between .1 and .2 sec, with locations remaining in the left channel, and frequencies moving from a 1000 to 2000 Hz range to a 800 to 1000 Hz range.

SEE ALSO

cmix

BUGS

Event durations may be slightly different from what is specified.

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